quotas. But such a program runs the risk of becoming an entitlement for uncompetitive industries, even when technology would not appear to offer a solution to an industry's competitive handicaps. The government may wish to make clear its view that future protection does not logically follow from this type of program.

Finally, the Sematech program is sufficiently novel that it is not obvious where in the government it should be located and funded. The Department of Defense has a series of programs related to technological development and the semiconductor industry and is interested in preserving the technological prowess of the defense industrial base as a matter of policy. Yet its major accomplishments in semiconductor R&D consist of "driving" technology to new levels of performance with only secondary regard for cost. The department has little experience in promoting technology that has immediate commercial applications and is cost effective.

A proposed alternative to the Department of Defense is an ad hoc committee with representatives from DoD, the Department of Energy and its National Laboratories, and the National Science Foundation's Engineering Research Centers. Such a committee would reflect the broader interests of the federal government and provide more diverse expertise, but would have to be organized quickly in order to establish policy and budgetary priorities and to hire staff. The existing proposal for an ad hoc committee gives it a full-time staff of only seven; the rest would have to come from the participating federal agencies.

CHAPTER I

INTRODUCTION

A common perception, both inside and outside the semiconductor industry, is that U.S. producers are losing their competitive edge to Japanese firms. This perception has led to a number of proposals for action, the most prominent of which calls for the federal government to join in the funding of a research consortium of semiconductor producers and suppliers of semiconductor manufacturing equipment. The aim of the consortium, known as Sematech, is to improve the manufacturing technology of the U.S. semiconductor industry, an area of widely acknowledged weakness. Under the current proposal, the federal government would provide a total of about $600 million over the next six years--almost half of Sematech's total budget.

The Sematech proposal raises a series of important issues. The industry and the proponents of Sematech have focused on whether the United States has lost its competitive lead in semiconductor production to Japan. Evidence (presented in Chapter II) suggests that the lead has been lost mainly in the production of semiconductor memory devices for the open market and in some aspects of manufacturing technology. Although the advantages held by Japanese companies have yet to translate into market dominance, they could do so, if sustained. Another, and more important, issue is whether the relative decline of the domestic semiconductor industry is a matter for public concern. This is the question addressed in this report.

THE PUBLIC INTEREST IN THE SEMICONDUCTOR INDUSTRY

Change is a fact of economic life. Industries and technologies have cycles, and the fortunes of particular firms and industries--while of concern to the people most closely involved--are not typically grounds for federal intervention. Proponents of Sematech argue that the semiconductor industry is different because it contributes to the national welfare in ways that extend beyond the usual measures of output and employment. The public interest in the semiconductor industry stems from the industry's contributions to national security, to improved productivity in its own and other industries, and to the overall advancement of science. From a public policy perspective, the decision to support Sematech may hinge more on its contributions to the overall national welfare than on its narrow ability to help U.S. firms outproduce foreign competitors.

As will be discussed in Chapter III, the semiconductor industry ranks high on these measures of national welfare. Areas of national concern would include the loss of the "spillovers" provided by a dynamic semiconductor industry. These spillovers occur when the research and development performed by one firm within the industry benefits another, and as lower costs of integrated circuits in turn result in lower costs of computer, robotic, and other electronic equipment throughout the economy. Moreover, the semiconductor industry is a repository of much of the scientific and technical talent in the economy, somewhat akin to a university. Just as the decline of the nation's major universities would be a concern, so may the condition of its science-intensive industries.

In addition, semiconductors are increasingly important to U.S. weapons programs. The actual number of semiconductors consumed by the Department of Defense (DoD) represents only a small fraction of the total produced in the United States and, consequently, quantitative shortages are not likely to be the issue. But a dependence on foreign semiconductor technology might place further constraints on U.S. foreign policy and might lead to a deterioration of the technological base of the U.S. industry, upon which DoD relies.

CURRENT FEDERAL SUPPORT

The federal government is already significantly involved in the U.S. semiconductor industry. Many of the current and proposed programs of special assistance to the U.S. semiconductor industry are based on the industry's analysis of unfair foreign competition. The perception within the U.S. semiconductor industry is that U.S. producers lost this market because their industry had been targeted by the Japanese government.1/ The major elements of this alleged targeting included the closing of the Japanese market to U.S. semiconductor devices as soon as equivalent Japanese devices became available, Japan's Very Large Scale Integration (VLSI) cooperative research project (in which the government provided seed money for cooperative research into VLSI manufacturing technology), and the vertically integrated structure of the Japanese electronics industry, which may allow production of semiconductors to be subsidized by the production of electronic goods containing semiconductors.

At present, the most substantial federal involvements with the industry are its funding of semiconductor research and development (R&D) and the U.S.-Japan Semiconductor Accord. The accord negotiated between the two countries, which is outlined below, is intended to reduce the market barriers in Japan for U.S. semiconductors and, by setting minimum prices, to eliminate the possibility of cross-subsidizing semiconductor production. The Sematech manufacturing consortium, which is supposed to bring U.S. manufacturing capabilities up to the level of those in Japan, is patterned after the VLSI project.

Federal Research and Development Programs

The debate over the possible federal role in Sematech may obscure the already substantial efforts of the federal government in semiconductor research. Federal agencies have been involved in the U.S. semiconductor industry since its inception and have contributed to its competitiveness. Furthermore, federal agencies spend far more on semiconductor R&D than does the government of Japan, although not all U.S. spending is related to commercial efforts.

Federal agencies will spend an estimated $400 million to $500 million in 1987 on research into semiconductor materials, design, and manufacture (see Appendix A for details). The largest amounts (over $300 million) are being spent by the Department of Defense. Most of their research, however, has only limited short-term commercial

1. The Semiconductor Industry Association (SIA) has several publications on this theme. See, for example, *Semiconductors & U.S. Competitiveness* (Cupertino, Calif.: SIA, February 1987).

potential. The Department of Energy's National Laboratories also have research programs on semiconductor materials and processing, totaling almost $80 million. The National Science Foundation spends $30 million on semiconductor research, although most of its money is for basic research in such areas as the structure and characterization of materials. The National Bureau of Standards spends $5 million a year developing technology to measure semiconductors.

Although federal agencies already spend a great deal on what appears to be support of the semiconductor industry, most of this money is spent to develop military and other noncommercial uses of semiconductors rather than to further manufacturing technology. The largest amounts of funds are spent to develop radiation-hardened (rad-hard) integrated circuits, which are used solely in military or space applications, represent only a small fraction of semiconductor sales, and have only limited commercial potential.

The other major federal research effort involves the use of semiconductor materials other than silicon, most notably gallium arsenide. Although these materials may become increasingly important in the future and indeed may very well replace silicon as the preferred material for semiconductors, silicon will probably dominate the commercial market for the remainder of this century.2/ Thus much of the federal research dollar, while financing materials research with future applications, is spent acquiring knowledge of little immediate commercial relevance.

This last conclusion points to a gap in current federal funding of semiconductor R&D that in turn may not be covered by semiconductor firms or their suppliers of manufacturing equipment. Outside of radiation hardening, which is primarily for federal use, much federally funded semiconductor R&D is basic research that will become commercially important only in the next century. By contrast, semiconductor companies concentrate their manufacturing R&D on solving current problems or providing background for their next manufacturing facility. The middle range of R&D--falling somewhere

2. James Meindl, "Future Needs of Ultra-Large Scale Integration," in Semiconductor Equipment and Materials Institute, *Forecast: The Business Outlook for the Semiconductor Equipment and Materials Industry, 1987-1989* (Mountain View, Calif.: SEMI, 1987), p. 2.

between the next factory and the next century--is thus often alleged to be missed by both federal agencies (and presumably their sponsored R&D at universities) and private firms.3/

The U.S.-Japan Semiconductor Accord

The semiconductor accord signed by Japan and the United States in the summer of 1986 represented a major departure of federal policy and a new level of federal involvement in the semiconductor industry. By forming a cartel comprising the world producers of semiconductor memory devices and guaranteeing U.S. producers of integrated circuits a minimum price, U.S. trade representatives hoped to improve the financial circumstances of the U.S. producers. This spring the U.S. government enforced cartel pricing by imposing duties on Japanese goods for selling at below-market prices in other countries. Subsequently, the Japanese Ministry of International Trade and Industry (MITI) put pressure on Japanese producers of semiconductors to reduce production of dynamic random access memories (DRAMs), and the Administration has now begun to reduce the tariffs.4/ Ironically, the resulting DRAM shortage is threatening to stifle the recovery of the semiconductor industry that began earlier this year. Thus, having spent two years pressuring the Administration for the accord, U.S. semiconductor producers now want the enforcement reduced.

Terms of the Accord. The complete terms of the semiconductor accord have never been made public. While much information is available, details about several of the provisions have not been clarified. The published version of the accord has two central provisions. First, Japanese producers of semiconductors must sell their memory chips at or above their average cost of production, or fair market value, as

3. For this argument, see Deborah Shapely and Rustum Roy, *Lost at the Frontier: U.S. Science and Technology in Trouble* (Philadelphia: ISI Press, 1985).

4. DRAMs are the most widely used type of semiconductor device, accounting for between 8 percent and 10 percent of U.S. shipments of integrated circuits. For a more complete description, see Chapter II.

calculated by the U.S. Department of Commerce.5/ At present, however, the fair market values are only slightly higher than the U.S. market prices.6/ Second, Japanese consumers of semiconductors will increase the number of integrated circuits they buy from U.S. producers.

Implementation of the Accord. The implementation of the accord has been controversial from the beginning. The first calculations of the fair market values caused DRAM prices in the United States to quadruple overnight. Then disputes arose over pricing in third-country markets. MITI at first said it could not make Japanese semiconductor producers restrain their output. This lack of restraint caused a glut of DRAMs in Japan. Inevitably, some of these integrated circuits were exported to other countries for assembly into final products, and U.S. producers of electronic equipment found themselves hurt by foreign competitors who had access to "cheap" DRAMs. Only after the Administration threatened to impose trade restrictions was MITI able to persuade Japanese producers to reduce output. Despite MITI's efforts, the U.S. Administration imposed tariffs on $300 million worth of Japanese imports in retaliation for violations of the accord in third-country markets. Shipments by U.S. semiconductor firms are now increasing substantially, in part because Japanese firms reduced their production.7/

Sematech's Role

Sematech would marshal public and private resources in a collaborative effort to improve the manufacturing technology of the semiconductor industry. This focus would address both the industry's

5. The Japanese semiconductor producers provide the information on production costs to the Department of Commerce, which then calculates their average cost. The specific formula for calculating the fair market value is often used as one of the conventional tests for "dumping"--selling below costs. The details of the Department of Commerce calculations have not been made public and have been a matter of contention.

6. Minoru Inaba, "Hear 256K DRAM FMV About $2.80," *Electronic News*, June 29, 1987, p. 24.

7. "Semiconductor Firms Re-crank Idle Capacity," *Electronic News*, August 10, 1987, p. 1.

concerns about losing its competitive lead to Japan and federal concerns over advancing the national interests. Industry concerns would be addressed because Sematech would concentrate on an area that many independent technical experts agree needs to be improved. Federal concerns would be promoted through support for an activity--research relevant to the commercial manufacture of semiconductors--that has high potential spillover benefits, and is not adequately addressed in current federal R&D programs.

The emphasis on manufacturing technology--both in the proposal for Sematech and within the semiconductor industry--results from the common perception that this technology will be changing substantially in the near future. The demand for more powerful integrated circuits causes semiconductor producers to seek more from their manufacturing processes and equipment. Trends in the semiconductor industry are described in the next chapter. The details of the proposed consortium are outlined in Chapter IV.

CHAPTER II

OVERVIEW OF THE SEMICONDUCTOR INDUSTRY

The interest in establishing Sematech stems primarily from the perception that the competitiveness of the U.S. semiconductor industry is in broad decline. While the value of the Sematech consortium is more related to the social benefits it will create than to the competitiveness of the U.S. industry per se, conditions in the U.S. industry must be understood if only to identify Sematech's potential effects.

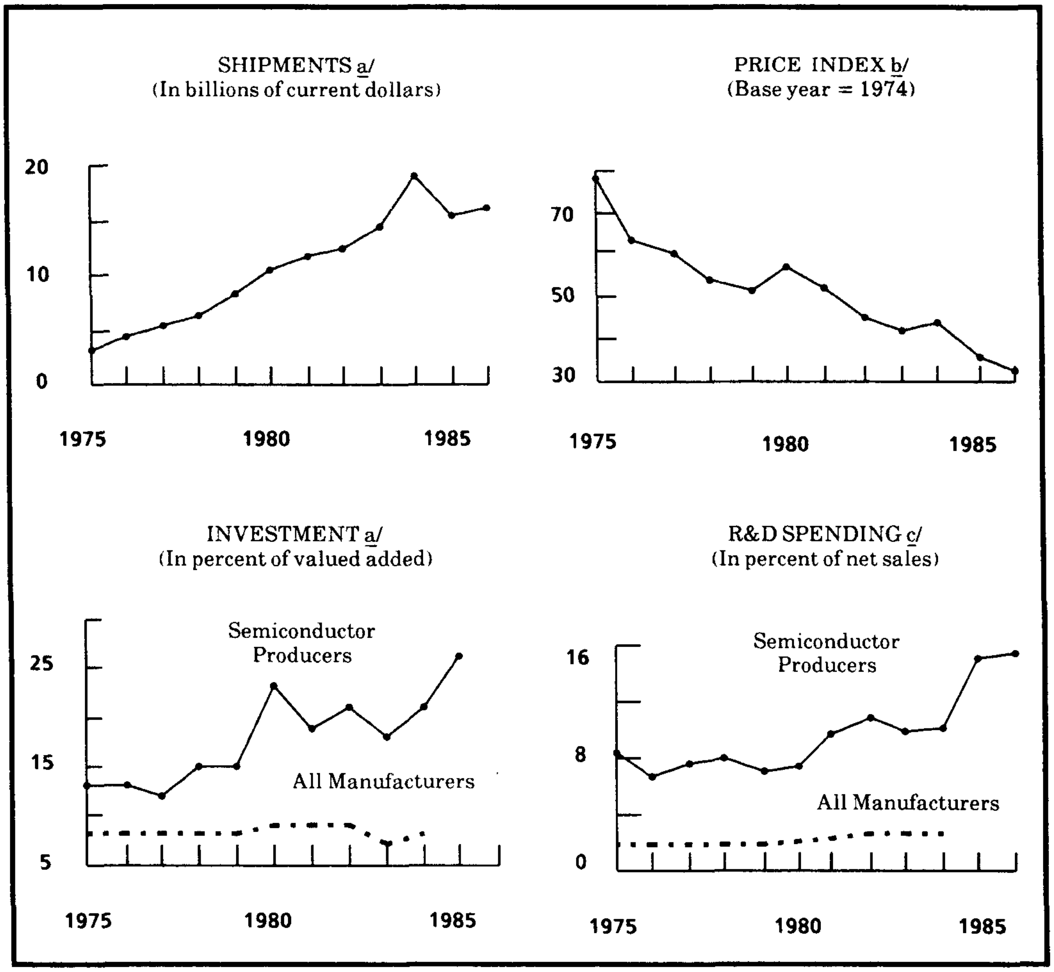
Although U.S. producers have largely been driven from the market for standard memory devices by foreign competitors, they retain their advantages in other devices used in manufacturing electronic goods. But U.S. firms have proved to be better at designing products than manufacturing them; the state of semiconductor manufacturing technology has been more widely recognized as a source of concern.

This chapter identifies important characteristics of the U.S. semiconductor industry--in particular, the portion of the industry that produces integrated circuits--and of the industry that manufactures equipment used in producing semiconductors. Appendix B presents a brief technical description of the range of products produced by the semiconductor industry and of semiconductor manufacturing technology. A glossary of technical terms appears at the front of this report.

THE U.S. SEMICONDUCTOR INDUSTRY

The U.S. semiconductor industry has grown quite dramatically since the early 1970s, as shown in Figure 1. In 1984, for example, shipments of semiconductors exceeded $19 billion. But this growth has not been steady. In 1981 and 1982, the rate of growth in semiconductor shipments slowed because the production of integrated

FIGURE 1. PERFORMANCE INDICATORS FOR U.S. PRODUCERS OF SEMICONDUCTORS



SOURCES: Congressional Budget Office using data from Department of Labor, Bureau of Labor Statistics; Department of Commerce, Bureau of the Census; Semiconductor Industry Association; and National Science Foundation.

a. Semiconductors defined as Standard Industrial Classification 3674. Data for the U.S. semiconductor industry include Japanese manufacturing facilities in the United States. There are relatively few of these facilities.

b. Price level of digital metal-oxide semiconductor (MOS) integrated circuits.

c. Semiconductor data for 1985 and 1986 are preliminary. The R&D data for the semiconductor industry come from the Semiconductor Industry Association (SIA). *Business Week* surveys of R&D suggest that the semiconductor industry R&D level (as a percent of sales) is lower than that reported by SIA (closer to three times its average of "all manufacturers"); see "R&D Scoreboard," *Business Week*, March 21, 1984. The data for "all manufacturers" are taken from National Science Foundation, *Research and Development in Industry, 1984* (Washington, D.C.: NSF, 1987, Table B-19).

circuits (which make up nearly 80 percent of the semiconductor market) by U.S. capital-affiliated firms stagnated.1/ The mid-1980s witnessed a temporary decline in semiconductor production as a result of lagging computer sales, although that now appears to have turned around and the industry is currently returning to economic health.

One indication of the advances made by this industry is the continual drop in semiconductor prices, also shown in Figure 1.2/ This price decline has two important implications. First, it indicates a significant increase in the productivity and competitiveness of semiconductor manufacturers, as they have managed continually to reduce production costs. Second, it implies an even greater growth in physical output than that shown by measuring only the dollar value of semiconductor shipments. As prices drop, more semiconductor units are produced per dollar.

The increase in shipments and drop in prices could not have occurred without substantial investments in both capital improvements and research. Figure 1 shows that the semiconductor industry has invested in both at a much higher rate than other manufacturing industries. The overall level of investment (as shown in Figure 2) accelerated in 1983--about the time that Japanese semiconductor firms began to penetrate the U.S. market. Although U.S. semiconductor firms have significantly increased their capital investments, they have still fallen behind Japanese producers. Capital expenditures by Japanese firms have grown steadily--from a level of about one-third that of the United States in 1979--and have now taken the lead. The European firms have not participated in the recent expansion of manufacturing capacity.

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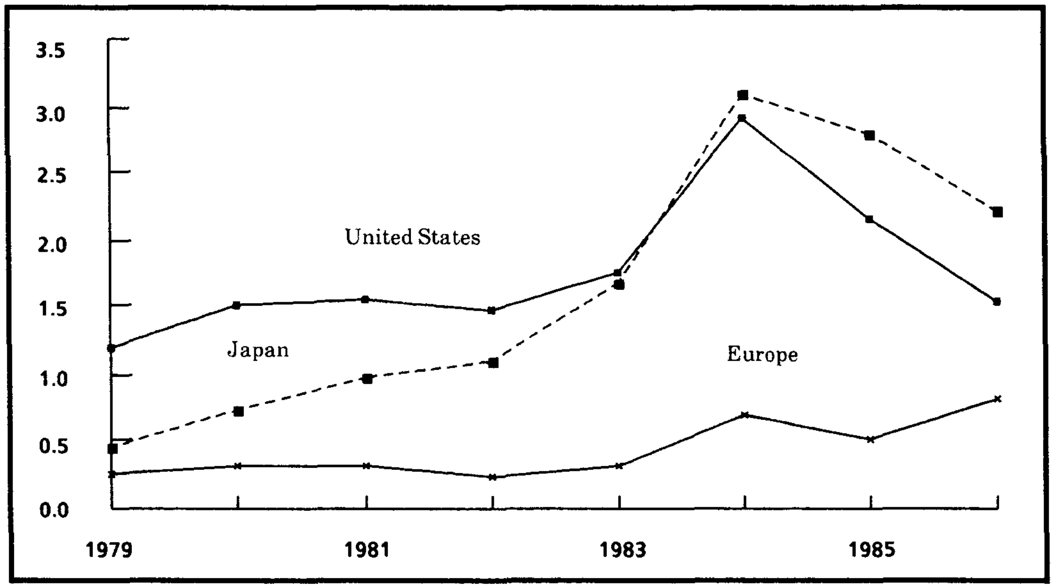
1. The definition of U.S., and foreign, capital-affiliated firms is an important one for understanding several issues raised later in this report. U.S. capital-affiliated firms are those that are predominantly owned by U.S. stockholders, regardless of where the firm's plants are located. Similiarly, foreign capital-affiliated firms are those owned by foreign stockholders, even if they operate plants in the United States.

2. Figure 1 shows the price decline of digital metal-oxide semiconductor (MOS) integrated circuits, which accounted for roughly half of U.S. semiconductor shipments in 1985.

FIGURE 2. CAPITAL EXPENDITURES BY SEMICONDUCTOR FIRMS IN THE UNITED STATES, JAPAN, AND EUROPE
(In billions of current dollars)



SOURCE: Integrated Circuit Engineering Corporation, Scottsdale, Arizona.

NOTE: Capital spending classified by country or region in which firm is based.

Structure of the Semiconductor Industry

Analysts commonly characterize the U.S. semiconductor industry as being composed of three types of manufacturers: **captive producers,** who produce only for internal consumption; **merchant producers,** who produce a broad range of semiconductor devices for the open market; and **niche producers,** who serve a specialized market with proprietary technology.

Captive producers manufacture between a quarter and a third of the total U.S. output.3/ International Business Machines (IBM), the largest U.S. manufacturer of semiconductors, accounts for between one-half and two-thirds of all semiconductors produced by captive

3. The problems in valuation of captive production and the proprietary nature of output make firmer estimates impossible. Devices produced by captives often have no commercial equivalent. Furthermore, attributing the R&D for such devices and differentiating it from system design are difficult.

firms.4/ Other major captive producers include American Telephone and Telegraph (AT&T), Hewlett-Packard, General Motors (Delco), Digital Equipment Corporation, Honeywell, and others.

The merchant producers are largely independent of firms that produce the electronic equipment or systems that employ semiconductors. Most of them are especially vulnerable to fluctuations in demand for semiconductors because they do not have large internal markets to shelter them. Of the big U.S. merchant producers, only GE-RCA, Motorola, and Texas Instruments produce enough electronic equipment to absorb some of their excess semiconductor production. In contrast, captive producers will attempt to keep their own capacity fully utilized before they turn to outside producers, insofar as they are able.5/

Niche producers specialize in one or more small families of products. Depending on how markets are defined, these firms may account for as much as one-seventh of all semiconductors produced in the United States. Proprietary technology and unique products give these firms a competitive advantage.6/ As so-called niche markets grow, many of them are becoming attractive enough for larger companies to enter.

4. See W. Edward Steinmueller, "Industry Structure and Government Policies in the U.S. and Japanese Integrated Circuit Industries" (Center for Economic Policy Research, Stanford University, December 1986), p. 25. See also Jack Beedle, "Semiconductor Industry Statistics, Analysis and Economic Trends--Past and Future," in Semiconductor Equipment and Materials Institute, *Forecast: The Business Outlook for the Semiconductor Equipment and Materials Industry, 1987-1989* (Mountain View, Calif: SEMI, 1987), p. 48.

5. Steinmueller reports that in 1985, while merchant production was undergoing its worst contraction of recent memory, the captive producers were actually increasing output. See Steinmueller, "Industry Structure and Government Policy," p. 35.

6. For instance, a handful of firms make special integrated circuits that allow personal computer manufacturers to make IBM-compatible computers at low cost by replacing many conventional integrated circuits with a few special ones. Given the potential cost savings here, the absolute efficiency required in the manufacturing of integrated circuits is not a consideration in this specialized market, whereas it drives market share in commodity memory markets. Bernard Cole, "Despite IBM's PS/2, the Outlook Is Bright for Clone-Chip Makers," *Electronics*, June 11, 1987, pp. 81-82.

Vertical integration (the entry of a firm into businesses that either supply it with resources or use its product) is not now the dominant form of business structure in the semiconductor industry. But this situation is changing; the first steps toward vertical integration of the merchant producers are now being taken through alliances between producers of semiconductors and electronic goods. This change is a logical progression from the semiconductor industry's early period of growth (pre-1980), which was characterized by the strong technological performance of independent firms, to the present, where the advantages of size and diversity have begun to play a more important role in business survival.7/

Competition With Japanese Firms

U.S. semiconductor manufacturing firms remain the world's dominant producers, although their lead is shrinking rapidly. In 1975, U.S. capital-affiliated firms produced three-quarters of all integrated circuits.8/ The export of semiconductors by Japanese firms to the United States increased sharply in the late 1970s when demand outstripped available U.S. supply. Japanese firms quickly became dominant in the sale of semiconductor memories, capturing a larger share of the U.S. market with each new generation of memory device. By 1986, the U.S. share had shrunk to 55 percent (see Figure 3).

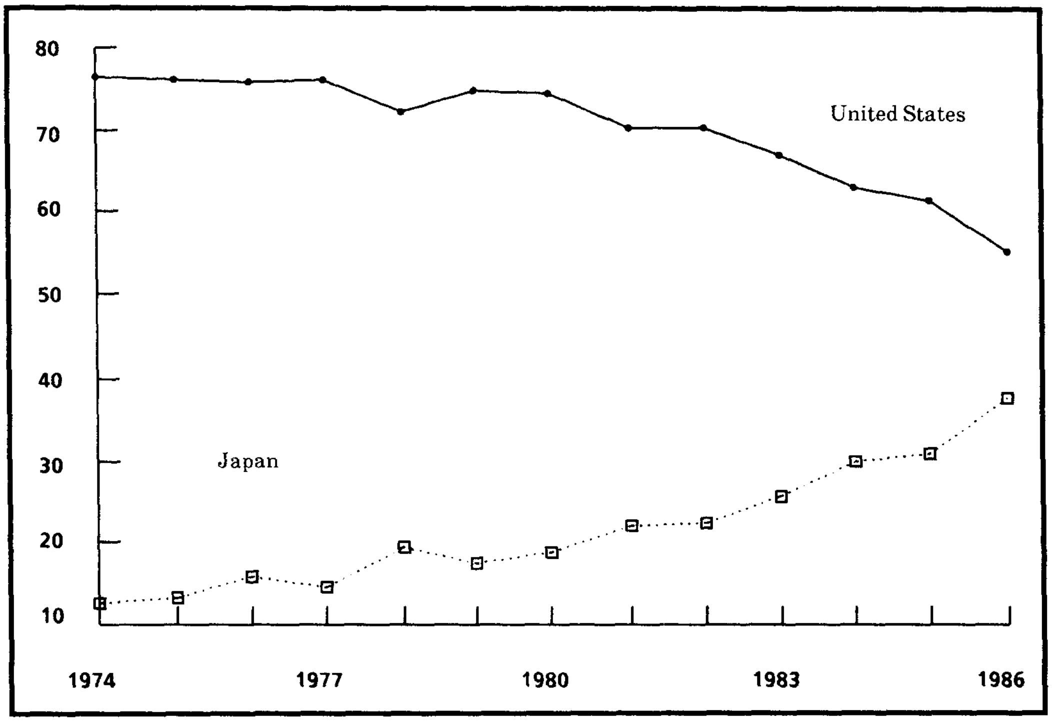
During the same period, the market share of Japanese capital-affiliated firms rose from 15 percent to 40 percent. The Japanese growth came largely at the expense of U.S. merchant producers, whose market share fell from 60 percent to below 45 percent of semiconductor devices traded on the open market.9/ In the closely

7. Steinmueller, "Industry Structure and Government Policies," pp. 32-42.

8. Exact estimates, while available, have a wide band of error associated with them. A significant percentage of total worldwide production is not traded but rather is consumed by the producing firms, which makes precise valuation impossible.

9. Department of Defense, Defense Science Board, *Report of the Defense Science Board Task Force on Defense Semiconductor Dependency* (February 1987), p. 5.

FIGURE 3. SHARE OF WORLD MARKET FOR INTEGRATED CIRCUITS HELD BY UNITED STATES AND JAPAN
(In percents)



SOURCES: Dataquest Inc., San Jose, California; and Integrated Circuit Engineering Corporation, Scottsdale, Arizona.

NOTE: Includes both U.S. captive and merchant firms.

watched market for dynamic random access memories (DRAMs), the U.S. share has plunged even more, going from over three-quarters of open-market production in the mid-1970s to less than one-quarter in the mid-1980s, even though absolute production rose.10/

The growth of foreign producers of semiconductors--particularly those in Japan--coincided with a severe worldwide downturn in demand for semiconductors in 1985 and 1986. Because of the simultaneous occurrence of these two events, many analysts have blamed the decline in the U.S. share of the semiconductor market on Japanese expansion. However, roughly two-thirds of the decline in U.S. production can be attributed to the drop in global demand, and

10. Ibid., p. 20.

only one-third of the decline resulted from increased production by Japanese and other non-U.S. firms. World production declined by 13.2 percent between 1984 and 1985, while U.S. production declined by 19.4 percent. Thus, even if every producer's share had remained constant, U.S. production would have dropped by 13.2 percent, or roughly two-thirds of its actual decline.11/

The semiconductor manufacturing industry in Japan is dominated by a dozen vertically integrated electronics firms to whom semiconductors represent a small fraction of sales, and who consume a large part of their output. Some analysts have argued that this arrangement allows Japanese firms to subsidize their semiconductor production with profits from consumer and other downstream (end-market) products.

Semiconductor Memories. Japanese producers employ a strategy of high-volume production to realize economies of scale, together with an emphasis on innovative processes. The production of DRAMs, for example, is generally more cost-efficient in Japanese than in American firms; American merchant producers appear to have ceded the DRAM market to the Japanese manufacturers.

Some U.S. industry observers now fear that Japan's domination of one generation of DRAMs will spread to the production of other devices at the cutting edge of semiconductor technology. Part of this concern relates to the critical role of DRAM production in the development and testing of semiconductor manufacturing methods.12/

11. Estimates for U.S. producers are based on data from Department of Commerce, *U.S. Industrial Outlook, 1987* (1987), p. 32-3; estimates for non-U.S. producers are from Dataquest Inc., San Jose, California. The Department of Commerce data include some Japanese semiconductor production in the U.S. total (because of their U.S.-based production) and exclude U.S. semiconductor production in Japan and Germany. Using only Dataquest estimates would change the relative proportions but not the implication.

12. DRAMs have two qualities that make them desirable from a manufacturing perspective, where the manufacturer wants to achieve technological superiority. First, their design is simple; a 256K DRAM consists mainly of 256,000 repetitions of a single memory cell and the interconnections. Thus, these integrated circuits are akin to a test pattern that allow producers to see their results clearly. Second, DRAMs are produced by the million. The need to produce millions of devices allows semiconductor manufacturers to learn from their mistakes and increase their yields.

But the DRAM is not the only memory device that can be used for this purpose. Static random access memories (SRAMs) and erasable programmable read only memories (EPROMs) also have been used for testing, and many U.S. firms still produce these devices, despite competition from Japan. Moreover, U.S. captive producers still make high-volume memory chips--firms such as AT&T and IBM continue to supply their own needs, including 256K and 1-megabit DRAMs. At least one merchant (Texas Instruments) still makes DRAMs for the open market.

Competition from Korean producers of semiconductors is also affecting the world semiconductor memory markets. Korea now exports leading-edge semiconductor products to the United States and hopes to become a leading supplier of semiconductors. Korean producers have explicitly targeted the Japanese segment of the semiconductor memory market.13/ Like Korea, other newly industrializing countries will probably be willing to take short-term losses to enter the semiconductor memory market in the future.

Microprocessors. Although Japan has made dramatic gains in the production of DRAMs, U.S. firms continue to lead in many important areas of semiconductor technology. U.S. makers of microprocessors now have an almost insurmountable advantage in software--there are tens of millions of computers and other machines that run on the software developed for U.S.-produced microprocessors. New microprocessors, if they are to compete, must be able to run that existing base of software as well as provide new capabilities. Thus, unless Japanese microprocessor makers got so far ahead of U.S. companies as to "leapfrog" this technology--a highly unlikely occurrence--the U.S. advantage appears secure.

13. For a discussion of the Korean semiconductor strategy, see Kim Chang-Kyong, "Out of the Laboratories and into the Factories," *Business Korea* (August 1984), pp. 27-35. See also Shelley Tsantes, "Lean, Mean and Hungry: Here Come the Koreans," *Electronic Business*, May 15, 1985, pp. 44-50.

The major challenge from Japan in the microprocessor market is in smaller, less expensive devices.14/ Japanese firms produce more 4-bit and 8-bit microprocessors than do U.S. firms; the United States, on the other hand, produces more 16-bit and 32-bit devices, which are newer and more expensive. When all four sizes of microprocessors are added together, Japan's physical output is greater, even though the output of U.S. firms has a higher dollar value.15/

Application-Specific Integrated Circuits (ASICs). The increasing sophistication of both the software that designs semiconductors and the integrated circuits themselves have made ASICs, which are designed for one narrow use, more attractive. Anxious to get out of commodity memory markets with their depressed profit margins, many U.S. producers have begun to produce ASICs. The rapid growth of ASIC markets--one estimate suggests that ASIC sales will quadruple by 1992--also attracts companies.16/ Despite the vaunted U.S. advantage in design, Japanese companies are also a major force in this area. One recent industry study suggested that three of the five largest ASIC producers, including the leading producer, are Japanese.17/ Part of their success derives from their long-standing concentration on custom design of integrated circuits for consumer products and electronic systems, which constitute a greater share of the Japanese market, as shown in Table 1. Although the initial designs were not particularly sophisticated, they gave the Japanese industry a solid foundation in this area. Now Japanese firms have begun to make substantial investments in design facilities in the United States to give them bases from which to work. The reputation

14. Another challenge to U.S. dominance of the microprocessors market may come from the Nippon Electric Corporation's (NEC) attempt to manufacture a proprietary microprocessor completely compatible with the Intel 8086/8088 microprocessor used in IBM-compatible personal computers. The NEC V series can run all the same software and at a faster rate than the Intel devices it replaces. NEC's design, however, may have constituted a copyright infringement. The U.S. courts are now deciding this case. For a short history of the case and trials, see the June 1986 issues of *Electronic News*.

15. Shelley Tsantes, "Microprocessors: Who Buys What and Why," *Electronic Business*, October 15, 1986, pp. 90-93.

16. Stan Runyon, "The Great ASIC Wave Gathers Force," *Electronics*, August 6, 1987, pp. 58-59. See also Steinmueller, "Industry Structure and Government Policies," p. 50.

17. "ASIC Top Ten," *Integrated Circuit Engineering News* (June 1987).

TABLE 1. END-USE MARKETS FOR INTEGRATED CIRCUITS, BY REGION (In percent of 1986 total consumption)

	All Regions	U.S.	Japan	Europe	Other
Military	7	15	0	5	0
Industrial	13	12	10	18	13
Telephone	19	18	18	27	14
Consumer	29	15	39	30	53
Computer	32	40	33	20	20
Total	100	100	100	100	100

SOURCE: "Where Do the ICs Go?" *Integrated Circuit Engineering News* (March 1987).

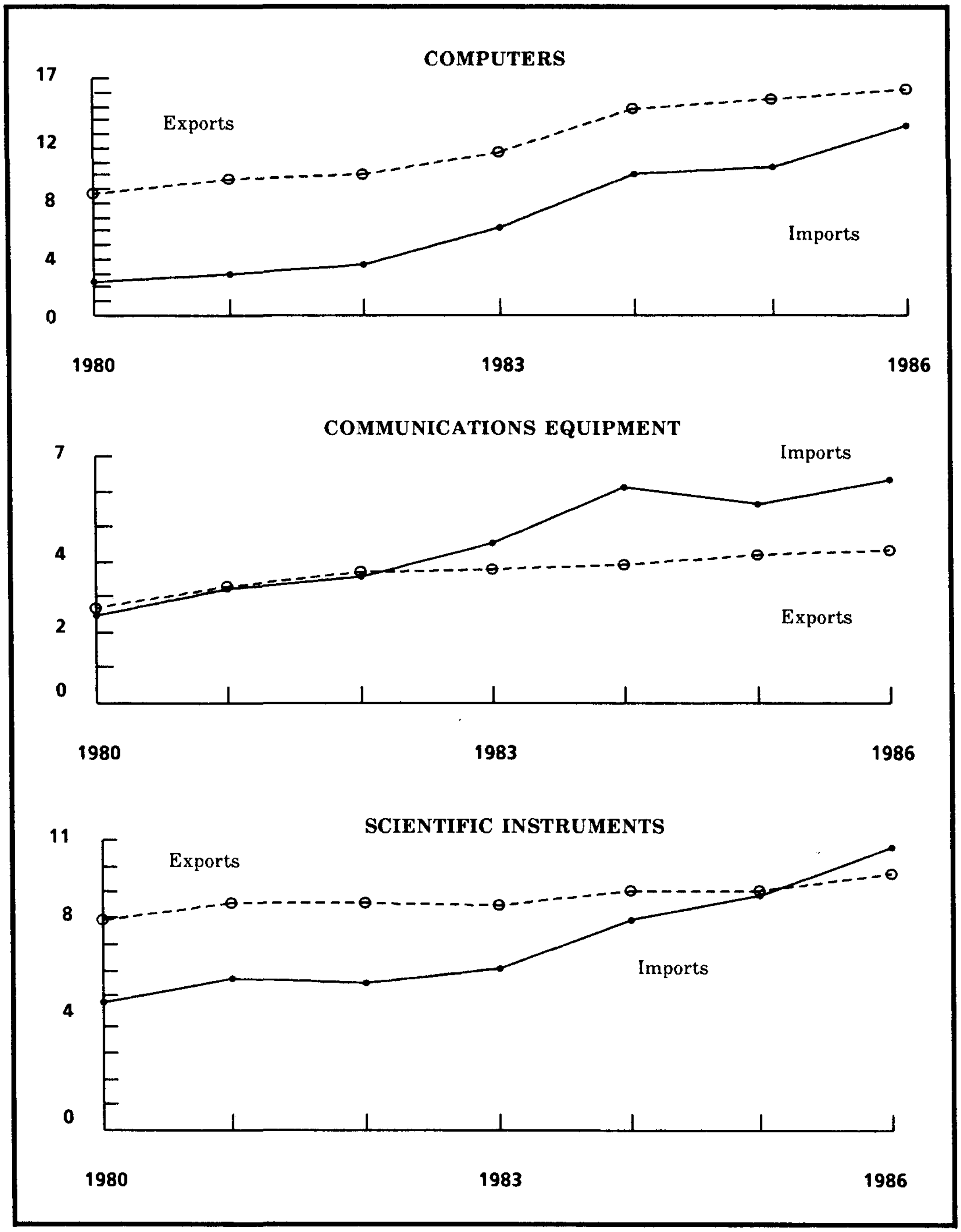
NOTE: Consumer includes automotive use. Computer includes data communication.

of Japanese firms for service has also helped them in this market, as ASICs are very service-intensive.

Electronic Goods. The U.S. domination of sophisticated electronic equipment also eroded in the 1980s, as seen in Figure 4.[18] The deterioration may have had more to do with the budget deficit and the value of the dollar than with any technological decline. But foreign producers, having made substantial inroads, are not likely to allow U.S. firms to regain their former market shares without vigorous competition, and will be drawn to invest in semiconductor manufacturing technology to reap the economic benefits of vertical integration. In fact, the loss by the United States of its share in the world semiconductor market to date has followed its decline as a supplier of electronic goods. As Japanese, Korean, and other firms have begun to supply more electronic equipment, they have used their own components, including semiconductors, to produce that equipment.

18. For more details, see Congressional Budget Office, *The GATT Negotiations and U.S. Trade Policy* (July 1987), Chapter III.

FIGURE 4. U.S. EXPORTS AND IMPORTS OF ELECTRONIC EQUIPMENT (In billions of current dollars)



SOURCE: Department of Commerce, Bureau of the Census.

NOTE: Computers includes all trade in Standard Industrial Classification (SIC) 357 Office and Computing Machines. Communications Equipment includes all trade in SIC 366 Communication Equipment. Scientific Instruments includes all trade in SIC 38 Instruments and Related Products.